Portal to Knowledge: a Virtual Library using Marker-less Augmented Reality system for Mobile Devices

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ABSTRACT

Since exceedingly efficient hand-held devices became readily available to the world, while not being a relatively recent topic, Augmented Reality (AR) has rapidly become one of the most prominent research subjects. These robust devices could compute copious amounts of data in a mere blink of an eye. Making it feasible to overlap computer generated, interactive, graphics over the real world images in real-time to enhance the comprehensive immersive experience of the user.

In this paper, we present a novel mobile application which allows the users to explore and interact with a virtual library in their physical space using marker-less AR. Digital versions of books are represented by 3D book objects on bookcases similar to an actual library. Using an in-app gaze controller, the user's gaze is tracked and mapped into the virtual library. This allows the users to select (via gaze) a digital version of any book and download it for their perusal. To complement the immersive user experience, a continuity is maintained using the concept of Portals while making any transition from AR to immersive VR or vice-versa, corresponding to transitioning from a "physical" to a virtual space. The use of portals makes these transitions simple and seamless for the user. The presented application was implemented using Google AR Core SDK and Unity 3D, and will serve as a handy tool to spawn a virtual library anytime and anywhere, giving the user an imminent mixed sense of being in an actual traditional library while having the digital version of any book on the go.

Keywords: Mixed Reality, Marker-less AR, Virtual Library, AR Core, Mobile AR, Augmented Reality Library

1. INTRODUCTION

In a recent study by Sansone et al[16] it was shown that the modern society, especially the young generation, is reclining progressively towards the digital realms for almost any kind of solution. With changing tides, it has become imperative for the organizations to serve their purpose through the medium that their users are most familiar with. One of the common example of such organization is a library. For some, due to the tedious taxonomy and specific jargon, it is really hard and often frustrating to navigate their way through the library without any special aid. While some prefer not to go to the library at all because of the unavailability of any in their vicinity. In this paper, we present a novel mobile application, named "Portal to Knowledge", which serves the exact purpose of providing users with an experience of going to an actual library without physically going there. Using our application, users can drop a portal to their personal library anywhere and anytime they want. The application employs marker-less AR technology which enables users to roam freely inside their virtual library, browsing books, without worrying about losing the track of AR markers.

As AR is not a very recent technology, due to the paucity of devices with good processing power and their unavailability amongst public before a couple of decades, applications of AR were only limited to Head Mounted Displays (HMDs) and hence, expensive research. After the introduction of hand-held devices with lightening fast processing speeds and graphics rendering powers, AR has gained it's now known fame. Augmented Reality simply means to present the real actuality augmented by an additional layer of contextual computer generated

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content to enhance the overall immersive experience of the user. As per Azuma et al in,[1] this additional content is superimposed on the user's field of view, complementing his/her visual perception, and not completely replacing it. In,[2] Craig et al also suggested that this additional information should be spatially and temporally registered with the physical world and should be interactive in real-time,[21],[22],[23] This makes it a little different from Virtual Reality (VR). In VR, the user's field of view is completely replaced by the virtual content which gives him/her the sensation of actually being in a whole different virtual world.

2. BACKGROUND AND RELATED WORK

Below we present a brief history and an overview of the state-of-the-art. We have categorized the related work in terms of (a) a brief overview of VR, (b) a brief overview of AR and various tracking methods, and (c) enhancing library experiences.

2.1 A brief overview of VR

Virtual Reality and Augmented reality systems can both be used to display digital content to the user and enhance or completely replace the user's perception of the real world at that moment. Commonly, VR is defined as an immersive system in which an HMD completely blocks the user's field of view and replaces it with two small high resolution stereoscopic screens. These two screens then display the virtual computer-generated environment to the user which can be explored and interacted-with in real-time.[18] Because of the technological and hardware limitations, there weren't many HMDs available to public before the period of 90's. Though Virtual reality is quite an old topic of research, the term was popularised by Jason Lanier when he first launched the Dataglove, during 1987 which was then used by NASA in it's VIEW system, and the EyePhone, making it the first commercially available VR solution to the market. Nowadays, consumers have a wide range of alternatives for their VR needs to choose from ranging from PC-based VR to haptic gloves and full body haptic suits.

Few of the best examples of recent publicly available PC-based VR HMDs are the Oculus Rift and HTC Vive. Both the HMDs consists of 1080×1200 resolution displays for both eyes and a field of view of 110 degrees making them highly immersive to the user. These HMDs have ruled the market since 2016, until recently when HTC launched an upgrade of it's vastly famous HMD, Vive. In April of 2018, HTC launched Vive Pro, with wireless functionality and with a 78% increase in the resolution of it's predecessor making it even more immersive to the user. While these are some of the best PC-driven VR solutions, there are also various mobile VR devices. Treating two halves of the phone screens as individual stereoscopic screens on the user's eye, we can get the similar immersive effect at a reasonably lower cost and better overall performance.[19] Few of the good recent examples using this technique are Google Cardboard, Samsung Gear VR and Google Daydream.[20]

Another variation of immersive VR is using a CAVE. A CAVE is a virtual reality system which enables users to experience virtual environments in a fully immersive way. It consists of four projection screens (three back-projections, one front projection) where stereoscopic images are being projected. The user can literally walk-in virtual environments and move freely in the area. Further exploration and interaction can be achieved through the use of other specialised equipment, such as data gloves, etc as in.[42]

The user can perceive the stereoscopic images using a pair of active stereo glasses in 3D, therefore increasing the sense of immersion and reducing the gap between physical and virtual reality. Moreover, the users head movements are tracked in real-time and are translated in movements in the virtual environment. Thus, by moving in real space the system automatically adjusts the projections according to the users current position and point-of-view, giving a more realistic feel. Although a number of successful applications have been reported,[41] a CAVE is not considered cost-effective in most scenarios.

2.2 A brief overview of AR and various tracking methods

Augmented Reality is a technology with which the vision sense of any human being is enhanced by superimposing some additional computer generated, context related, information onto their field of view. We can trace the first ever example of AR technology all the way back in 1968,[3] when Ivan Sutherland made the headset for the Sword of Damocles. Although the headset is taken to be the prime example for a VR system, one can fairly argue that it was the first example of an AR system as the headset proposed by Sutherland was partially transparent.[4] Mainly,

AR is used to enhance the user's visual perception of the real world but is not just limited to that. Researchers have also implemented the concept using high definition spatial audio to help blind people navigate in their day to day lives.[24] Few of the most recent, famous and commercially available AR headsets are Microsoft Hololens, Magic Leap One and Meta 2. But the refined circuitry and many sensitive systems like spatial mapping, voice recognition and gesture recognition makes it too costly for the consumers to buy it for their day to day lives. Because of this costliness, Mobile AR (its equivalent for mobile devices) is becoming more and more popular amongst the consumers.

In the case of mobile AR, techniques used for tracking the environment were dramatically improved after the introduction of better hardware which could compute thousands and thousands of bits of data in real-time. From around 2011, since the hand-held AR supporting devices became readily available to the public, one can see a dramatic surge in the research conducted on AR which, according to Akayr et al in,[5] was only going to escalate by 2012. We have also observed advancements in the process of registering the additional 3D content with the real world and maintaining its spatial continuity from the user's perspective.[4] One such advancement in the field of environment tracking and 3D content registration was the introduction of vision-based tracking systems.[6] In these types of systems, spatial data of the user with respect to his/her surroundings is extracted using computer vision algorithms,[7] which takes a RAW RGB camera feed as it's input and detects and tracks the feature points such as contrasting colors in textures of the scene, edges, corners etc.

Easily trackable images, such as predefined markers, were predominantly used in AR systems to directly register and track the 3D content before the introduction of Marker-less tracking algorithms. Few of the good marker-based AR application examples are[11][10][13][14].[12] However, the main limitation in such systems is that in most of the marker-based AR applications, the user is constrained in his/her movements with the AR device as he/she has to face the camera towards the marker at all times. This limitation is manageable for tiny play-spaces with multiple markers and hybrid approaches but it requires an efficient marker-less approach for larger play-spaces. One such hybrid approach was presented by Li et al in[15] where the authors proposed a hybrid approach to extract the user's spatial information using markers and the built-in gyroscope of the AR device. This system was better than any other simple marker-based AR application, but it still required further improvement to get rid of the markers completely.

When researchers realized the need for marker-less systems, many different techniques for tracking the environment without any markers emerged. Some researchers used Scale-Invariant Feature Transform (SIFT) algorithm for the registration of their 3D contents,[8] while some used Speed-ed Up Robust Features (SURF) as their base feature extraction and tracking algorithm.[9] Perhaps the most famous algorithm was Simultaneous Localization And Mapping (SLAM). This is a technique to derive a three dimensional geometry from a systematic range of two dimensional images alongside with the rotational data from the gyroscope of the AR device. A bigger scale variant of this algorithm is known as Structure from Motion (SfM). SLAM determines the depth of any feature point in a scene by triangulating the 2D feature points in two different images[27] and creates a three dimensional mesh after scanning all the detected feature points. Most popular examples of marker-less mobile AR SDKs are ARToolkit (by ARToolWorks) and Google AR Core. The application presented in this paper uses the latest version of Google AR Core to track the environment and maintain the position of virtual objects in their relative physical space.

2.3 Enhancing Library Experiences

Since the widespread availability and use of AR supporting mobile devices, mid 2010s, people have noticed some significant applications of this technology in Educational Industry. Amongst people predicting the digital age being our future and complex taxonomy systems used by the traditional libraries, an ample amount of opportunities became evident in the library sector of the educational industry that it became imperative for the librarians to move towards a hybrid model and introduce their services on a more familiar and widely used platform. By now, researchers have also realized the potential of this technology in libraries and started working on different applications and conducting surveys to help the librarians make a fully informed decision. Current state of AR was examined[28] and studies on the expanding use of AR and VR in educational industry (libraries) were conducted.[29] In this section we explore several articles that encouraged libraries to use AR technology to somehow aid the patron's overall experience. A better path-finding for the library users, the ability to highlight

exclusive bookshelves and also the aided shelf reading are some of the examples of several library services that were improved,[17].[29]

In,[30] Armstrong et al presented an initial version of an application under their SCARLET project which enhanced student's learning about primary as well as secondary sources in special collections using AR. It was found that in special collections environment, AR allows the students to experience both the sense of holding the actual material while simultaneously enhancing the learning ability by augmenting the contextual information around the object itself. Also similar to this, Arnhem and Spiller in[31] present a mobile AR system which enhances the patron's experience by providing additional information about the local art in the library of the College of Charleston. Apart from these, some scholars also suggested applications to facilitate new users ease their way into the library using various digital orientation methods. Few examples of such applications including other library related AR applications are,

- Audio-Visual tours using QR codes[32]

- Tours using tiny beacons and videos[33]

- ShelvAR: Mobile AR application for browsing and book shelf reading[29]

- AR-Game-based approach to learn the taxonomy of a Chinese library[34]

- Aurasma: Videos as AR overlays for self-guided library tours[35]

- Improving library navigation for children using AR[17]

- The SCARLET Project[30]

- Training library employees using QR Codes and AR[36]

Against the endless improvements in AR technology and its contextual applications, one can find only anecdotal evidence in the literature of AR technology assisting the use of library services without utilizing any actual, physical, library. In this paper, we present the novel marker-less mobile AR application: "Portal to Knowledge" which digitally replaces the physical library with a virtual while preserving the user experience of the traditional library.

3. APPLICATION OVERVIEW: PORTAL TO KNOWLEDGE

In this section, we describe the processes involved in the design and creation of the application which are divided into the following four subsections: (a) Tracking using Google AR Core, (b) Application Run-time Flow, (c) Creation of Book and Library Models, and (d) Creating the Portal.

3.1 Tracking using Google AR Core

The proposed AR application was developed with Unity 3D Game Engine and AR Core Software Development Kit (SDK) for Android devices. The latter is an SDK developed by Google which is mainly used for tracking the user's current positional and rotational information in physical space, and in real-time. In order to give the users an immersive, seamless and realistic experience of the AR virtual library, we utilized several built-in features of this SDK in our application. To determine the user's local position in the real world, Google's AR Core uses Concurrent Odometry and Mapping (COM).[37] Although the user's location in physical space is output from COM, to get more accurate positional and rotational data, this information is combined with the inertial measurements made by the Inertial Measurement Unit (IMU) of the mobile device. IMU is a small electronic device which consists of a bundle of sensors and meters such as accelerometers, gyroscopes and magnetometers. This small device (IMU) is used to measure specific natural or human induced forces and angular rates of the mobile device and report it back to the main processing unit. Using the information output from IMU, AR Core finally determine the orientation of the user in physical space.[38]

To make the tracking marker-less and even more accurate, AR Core detects and tracks feature points in the sequence of images captured by the device's primary camera in run-time. Once feature points are detected they are constantly tracked. If the feature points move outside the user's field of view, anchors are used[39] to relate the out-of-screen feature points with the screen's current content. Anchors are similar to landmarks we use to determine the specific address of any building. Once the additional digital content is dropped into the real world, some feature point is assigned to it. Hence this additional content is then tracked in physical space with respect to the feature point it has been assigned to. We call these type of feature points, anchors. Thus in terms of real world analogy, if you want to find some additional content in the physical space, you can look for the anchor point it has been assigned to and you will get to the object you were looking for.[40]

3.2 Application Run-time Flow

When the application is started, the user is prompted with a list of sections to choose from, having books related to different topics. Once a section of library is selected, AR Core initializes and removes any pre-stored information about the environment or the user's location in it from any previous instances of the application. Once the initialization concludes, the application displays the camera feed onto the device's screen as the AR background and starts searching for any surfaces in real-world to track. If a surface is found the application places a grid mesh on top for visualization purposes. A unique grid mesh with a unique color is assigned to every detected surface. Fig. 1 shows a white grid being superimposed on the detected surface i.e. floor. While users can control the visibility of these grid meshes, they can also place additional content on these surface as per their convenience.

Figure 1: Scanned surface visualized using a white colored grid mesh

Once the application assigns a grid to at least one surface, it awaits for the touch input from the user which will indicate where the door of the virtual library will be placed. When a touch input occurs, a ray is cast into the virtual space shown on the screen representing the tracked physical space from the user's point of view. If the ray intersects a detected surface, a feature point on that surface is created as an anchor and the virtual library is attached to it. In contrast, if the ray does not hit any surface the application continues to await for more touch inputs. Once the portal to the virtual library becomes visible, the user can enter through it (by walking straight into it) and explore the virtual space while actually moving in their physical space. Fig. 2 shows an example of what the screen displays once the user walks 'into the portal' transitioning from AR (as in Fig. 1) to VR by completely blocking the view of the real world.

Once the user is inside the virtual library the application awaits for the user to select a book. The selection is done using the gaze input method. Every book in the virtual library has a white, rectangular, gaze tag at the bottom of its visible side on the shelf. Fig. 3 shows a number of books with the tags on each book highlighted by a red circle. To use this input method, users have to focus the gaze pointer (a pink dot in the center of the screen) onto the tag of the book that they want to open for 1 second. This will trigger an event which in turn will, if it's not already downloaded, download the PDF version of the selected book, minimize the current application, and open this PDF on the user's device.

Once the user has finished perusing the PDF version of the book, he/she can return to the virtual library just by pressing the back button or reopening the application. The application will switch back to AR and continue

to track the environment, load the updated positional data from the device, and continue from where it left off. Thus, the user can peruse as many books as he/she wants to read within a single session. The flow chart showing the overall run-time flow of our application is illustrated in Fig. 4.

3.3 Creation of Book and Library Models

One of the final objectives of this work is its application to a large-scale context and in particular with the library of Concordia University. Through this collaboration we will incorporate thousands of books present in the library that are available in both, hard-copy version and the digital online version, into a compact virtual library AR application which can run on any pocket-sized device. For the purposes of the evaluation of the design of this application a generic 3D book model was designed using Blender. As previously mentioned, in the deployed application, each book will have its unique 3D model and texture. To create the generic asset, we used a Blender plugin called "BookGen" which allows you to create a stack of books on one go. In order to create books of different thickness, we created the stack with just one book and adjusted the dimensions of that asset approximately similar to the dimensions of the actual book. Once we had a texture-less book asset and the original book with us, we scanned the texture of the actual book and mapped it onto our 3D asset. All the sides were perfectly mapped on the exterior of the texture-less 3D book asset that we created, but the middle portion of the book, where we can see the sides of all the pages in the book, was still texture-less. An additional image was added with parallel black and white lines of different thickness to show the density of pages, in the texture mapping to cover that texture-less surface. This made our 3D book asset recognizable, and even more realistic.

The final 3D asset for the book is then imported into the unity project to be used as one book in our virtual library. The scanned texture of the actual book with the additional page density image and the final mapped 3D asset can be seen in Fig. 5a and Fig. 5b, respectively.

3.4 Creating the Virtual Portal

One of the main goals of the application is to give the users an immersive experience of enjoying the realistic, life-sized, virtual library while roaming in their physical space. To achieve this we employed the AR technology as the users in our application needed to move in their own physical space. The dilemma was that our library was completely virtual i.e. while exploring the virtual library, users will not be able to see anything from the real-world. Therefore, at one point or another in the application, we had to make a transition from being in a completely real-world to a completely virtual world i.e. our virtual library.

As we wanted to make the application as immersive as possible, transition from the real-world to the virtual world had to be smooth and seamless. There were several ways to implement this; one of which was by making the transition from real to virtual world (or the other way around) in a single cut i.e. very short time. Although this is too simple to implement and does not involve any heavy computations, it lacks the sense of continuity during the transition since the abrupt change in all the surrounding environment of the user was not at all smooth and seamless. Instead, another method was employed: that of fading the virtual environment into the
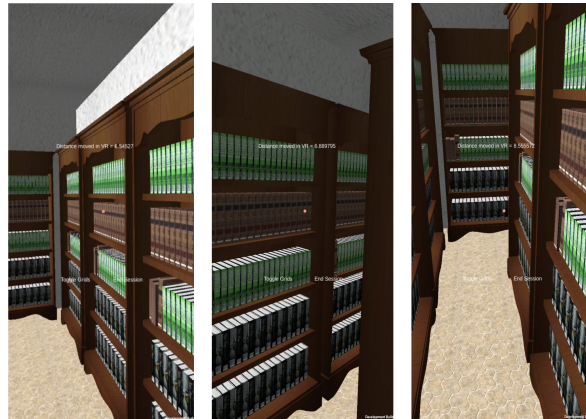

Figure 2: Inside the virtual library from user's point of view

Figure 3: Gaze tags highlighted by the red circles

scene while fading out the real world background. This was smooth, not perfectly seamless but better than the first method although it too lacked the sense of continuity that we were looking for.

After trying out several other methods, we finally decided to implement and use the Portal Effect for these transitions. In this method, the user would just have to place the portal in their physical space anywhere they want and walk right into the virtual library. When the user places the portal, it will fade in a simple door in his/her physical space through which he/she can simply walk and enter our virtual library. This method was more GPU intensive but the final effect was very smooth and seamless, and as we were using the state-of-the-art hardware, it didn't really effect the performance of the application. Also, as the user had to walk into the virtual library through the life-sized portal door, just like any other door in the real world, this method added a sense of realism and continuity to the transition that we were looking for.

To make the illusion of a portal, we had to display only a certain portion of the virtual library. This would be the only portion of the library which is visible from the user's point of view if he/she is looking inside the portal door. This had to be implemented such that the inside of the library is visible if the user is looking through the door but the normal real-world background should be visible around the portal door. Furthermore, the user should only be able to go inside the library if he/she walks through the portal door and not around it. This effect in our application was achieved using Shaders. For the area through which the user can see the inside of the library, we made the mask by a plane covering the whole portal door. A shader was applied to this plane which instructs the GPU to fill the stencil buffer for the area covered by this mask (plane) by the value of 1 instead of drawing on the screen. Given the mask, we applied another shader to all the materials of our library which gave commands to the GPU to only draw the fragments of the library where the value of the stencil buffer is equal to the value 1. Hence, if the user is outside, the application will only draw the portions of the library behind the portal door which are only visible through the mask. Once the user enters the portal, we remove the condition in all the virtual library materials to only draw where the value of stencil buffer is equal to 1. The application will always draw the virtual library irrespective of where the user is looking and when the user comes out of the portal, the condition in all the materials is again invoked to only draw where the value of stencil buffer is equal to 1. Fig. 6 shows screenshots of the portal effect, through various angles, from the outside of the virtual library while Fig. 7, shows screenshots of the same portal effect, through various angles, from the inside of the virtual library.

4. METHODOLOGY

For the evaluation of our application, we conducted a user study with a number of participants. The user study compared the user experiences of three different methods to retrieve an actual book or its PDF version. As previously mentioned one of our main goals was to give our users a realistic experience exploring the library at their own convenience and in the platform they are most familiar with. Since there is barely any other research literature available prior to ours exploring this concept, or any other similar approach to give users this kind of experience, we compared our technique of retrieving the book with that of a traditional library, and a simple online type and search method. We have divided this section in three subsections, one for each step in our
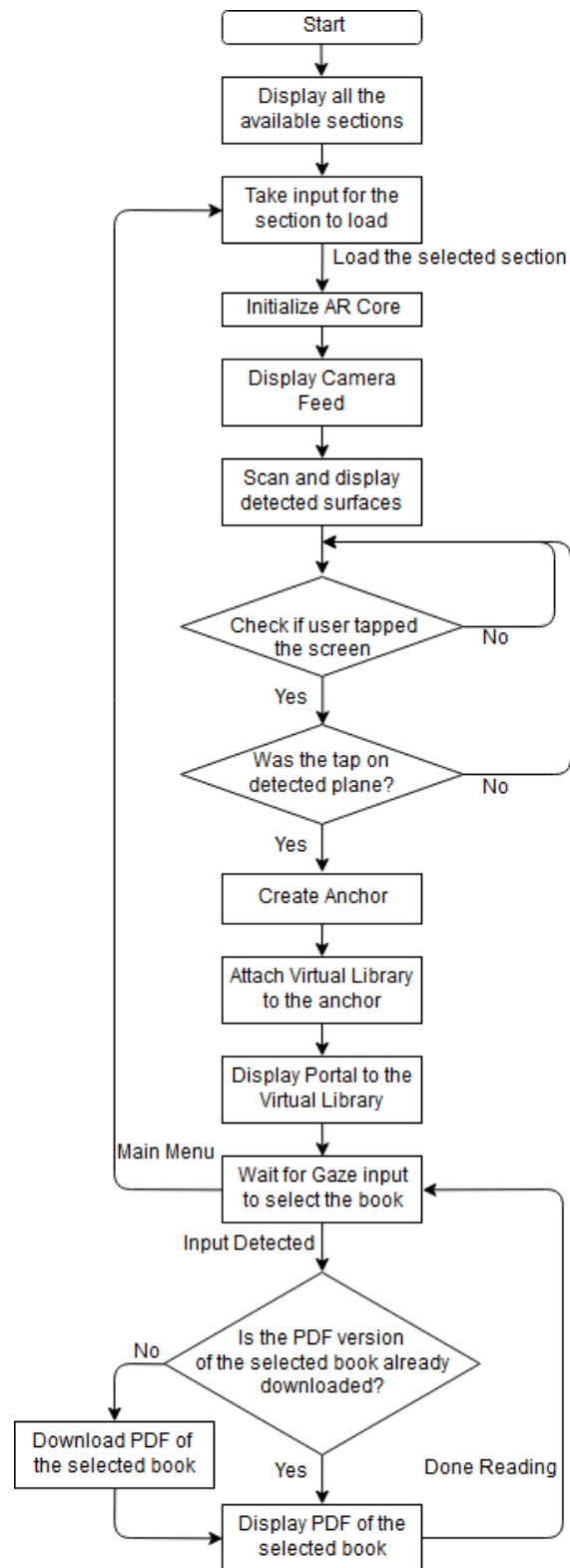
Figure 4: Flow chart showing overall workflow of the application

(a) Scanned texture of the actual book

(b) Final 3D asset

Figure 5: First image (a) shows the scanned texture of the actual book and the second image (b) shows the final 3D asset of the book used in our virtual library

Figure 6: Portal effect from outside of the portal

study: (a) pre-test questionnaire, (b) performing book retrieval tasks using different methods, and (c) post-test questionnaire.

4.1 Pre-Test Questionnaire

The main focus of the pre-test questionnaire was to derive the basic information about the demographics of the users, prior experience with AR, their current preference to the method of getting any book etc. At the beginning of the trial of the application, for every user, we requested that they fill out this questionnaire and provide us with some of this basic information about them. This information was vital for our study as it gave us a decent understanding of the crowd that we were dealing with, especially their familiarity with the AR technology and how comfortable were they using it.

Figure 7: Portal effect from inside of the portal

4.2 Performing Book Retrieval Tasks using Different Methods

We asked the participants to complete three simple tasks for this study: (i) downloading a book's PDF version and opening it on a desktop workstation, (ii) finding a book in a traditional library, and (iii) finding a book in the virtual library using our application.

4.2.1 First Task: Desktop method

In the first task, we gave users a standard desktop and a secure internet connection to browse on. We gave them the name of a book and asked them to find that particular book on any of the online libraries, download its PDF version into the hard drive of the system, and finally open that PDF on the desktop. While most of the users succeeded, several users who were not familiar with the online libraries or with using desktop computers, struggled a bit to finish this task. For most users, this task was too mentally demanding since they had to think a lot while making each and every click decision. As the task seemed too simple, users were trying to minimize the time and complete the task as soon as possible. Most of them succeeded, but the ones who couldn't find the book after looking into several google searches, they got too stressed out which in turn made their performance worse.

This task provided the users with an experience of using a Simple Type and Search method to retrieve the book.

4.2.2 Second Task: Search in Traditional Library

In the second task, we took users to our University's Library and gave them the name of a book. Users were then asked to find the book inside this seven-story library building using nothing more than just the title of the book. They had to use the library's computer-based search systems, and signs on the walls to reach a particular section of the library in which the book was shelved. Once the users reached their desired section they then had to go through all the books in that section and locate one book that was required in those shelves. As the library consisted of seven floors and the required book was placed on the fifth floor, this was a lot more physically as well as mentally intensive task when compared to the first task where the users just had to stay at one place and not move at all.

This task provided the users with an experience of using a traditional library method to retrieve the book.

4.2.3 Third Task: Portal to Knowledge

In the third and final task, users finally got to test the AR application and play around with it. Similar to the first two tasks, the primary job of the user was to find a book based on a visual description in the virtual library and open the PDF of that book on the device. Instructions on how to operate the application and interact with the books inside the virtual library were provided to the users before hand. Almost all of our users found the application to be more productive and convenient.

This third task was performed in an open airy space of around 7x10m^2 which is equivalent to an average large sized room. We used this large space to give our users more space to roam around, but our experiments have shown that one can easily perform the same task using our application with a space as small as 4x4m^2. This task provided the users with an experience of using our application to retrieve the book. Fig. 8 shows the available physical space (outdoors) that we used to complete this last step of the user study. This is the area utilized by the users to explore the virtual library and accomplish this third task.

4.3 Post-Test Questionnaire

In the post-test questionnaire, after the users completed all three tasks mentioned above, we recorded their feedback on locating a book either digitally or physically. In this questionnaire we included a number of questions for understanding the experience of our users and compare them amongst each method of retrieving a book. One of the important tests that we included in this questionnaire was NASA TLX, a scale to measure the overall workload of anything based on 6 different parameters. Using the NASA TLX, based on the mental demand, physical demand, temporal demand, effort needed, performance and frustration level, an overall workload can be calculated for the three task. On the scale of 1 to 5, we took the feedback for all the above mentioned parameters
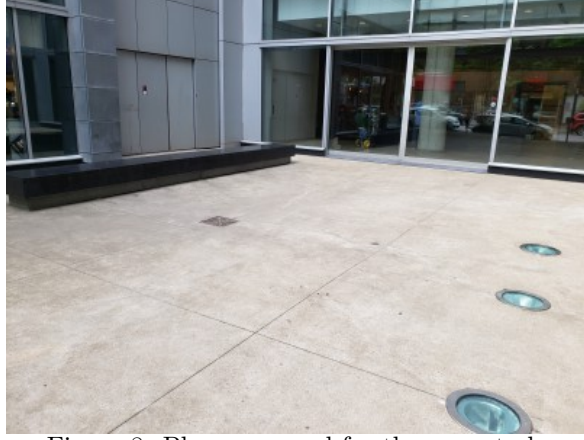
Figure 8: Play area used for the user study

for all three tasks from the user. This data helped us calculate the overall workload for all three tasks and hence compare it with each other.

Apart from these, the questionnaire took feedback on whether the users preferred (or not) our application over any other method and also if there is anything that can be improved. We also asked users about the convenience offered by the simple structure and portability of the application. The questionnaire took some additional information in the form of open questions about where the users generally faced issues while operating the application. Finally, we asked feedback from all the users about the overall rate that they would give to our application on a scale of 1 to 5.
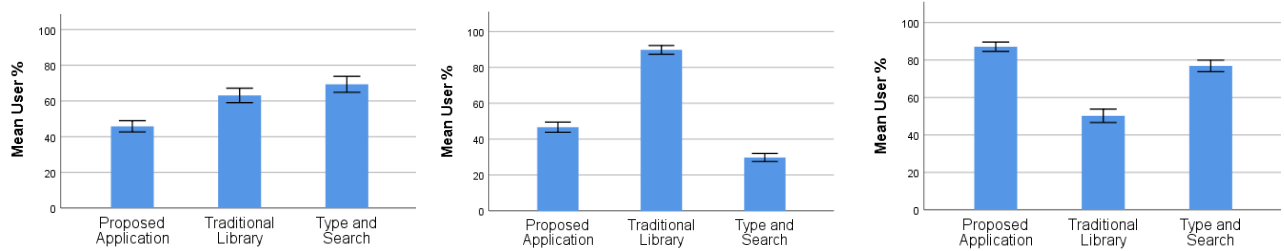

Figure 9: Left to right: ANOVA results for (a) Mental workload experienced by the participants. (b) Physical workload experienced by the participants. (c) Convenience offered by different methods. Error bars in all three figures is +/- 1*Standard Error.

5. ANALYSIS OF EVALUATION RESULTS

Filling up the post-test questionnaire was an end to the user study for one user. Once we collected all the data from each and every user, we performed a detailed analysis of the evaluation results. In this section, we preset an analysis based on various factors. It is mainly categorized into four different subsections: (a) participants overview, (b) analysis, (c) task load and, (d) user preferences.

5.1 Participants Overview

The user study was conducted amongst 45 participants out of which 20 were female and the age groups included are from 14 years to 44 years. The majority (64.4%) were from the age group of 18-34 years. Due to a vast diversity in the group of people that can be the potential users of this application, all of our participants were selected randomly and had nothing to do with their past experiences using AR. The participants were evenly spread among avid traditional and online library users, almost everyone was comfortable with using e-reading material on their mobile devices.
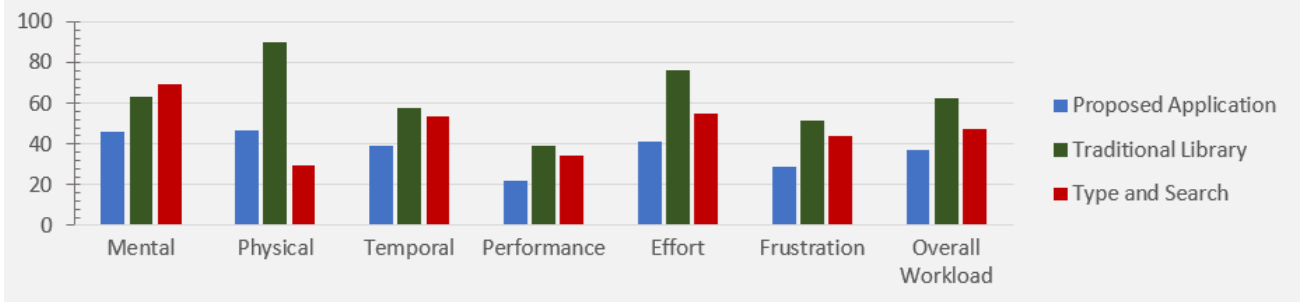
Figure 10: Average ratings out of hundred for six different workloads of NASA TLX questionnaire and the overall workload for each of the three methods

5.2 Analysis

ANOVA ($\alpha = 0.05$) with repeated measures was conducted for different methods of locating a book which includes our application, traditional library, and type and search. We had mental workload, physical workload and the convenience offered by the methods as independent variables for the test. Using Mauchly's test, we confirmed that the Sphericity assumption was preserved during the entire test. We used partial eta squared (η_p^2) to report the obtained Effect sizes.

5.2.1 Mental Demand

A repeated measured analysis of variance (ANOVA) was conducted to evaluate the amount of mental workload required in accomplishing a single task using our application, the traditional library approach and the simple type and search approach with a diverse group of participants ($N = 45$). The results of ANOVA showed a statistically significant effect of using different methods on the mental demand, $Wilks'Lambda = 0.67, F(2, 43) = 10.587, p < 0.05, \eta_p^2 = 0.33$. This gives us a significant evidence of mental workloads being different in each case.

As expected, the mental workload required to accomplish the tasks in the case of our application was the least. Followed by the traditional library method and topped by the simple type and search method. As the task seemed to be really simple when first given to the participants, most of them made a mental picture of how quick they would be in completing it before even they got on the internet. While failing to locate the book after making a few searches, a significant number of participants got frustrated and started to make even more blunders. This compromised their performance and increased their stress levels which in turn increased the amount of mental work done to accomplish the task. Although the difference between type and search, and traditional library is not very evident, the mental workload for our application is significantly less.

5.2.2 Physical Demand

We performed an ANOVA with repeated measurements test to evaluate the amount of physical workload required for the same tasks with a diverse group of participants ($N = 45$). The results of ANOVA showed a statistically significant effect of using different methods on the physical demand, $Wilks'Lambda = 0.15, F(2, 43) = 124.518, p < 0.05, \eta_p^2 = 0.853$. This gives us a significant evidence of physical workloads being different in each case.

Physical workload in case of the traditional library was found to be the highest as compared to any other technique. This can be attributed to the fact that the library used for this task was seven stories tall and participants had no clue on the where-about of the book. They had to roam a lot inside the library in order to get to the book. While in the case of Type and search, users had almost no physical workload as they just had to sit on a desktop and browse internet. Hence the physical workload observed in the case of type and search method was the least. Since users only had to walk in a small virtual room, in case of our application, the physical workload is not significantly higher than the type and search.

5.2.3 Convenience

Upon reapplying the ANOVA test with repeated measurements on the convenience offered by different methods, it showed us that there is an effect of using different methods on the convenience offered by those respective methods, and it is statistically significant. With 45 people in our survey ($N = 45$), the following results were calculated from ANOVA, $Wilks'Lambda = 0.38, F(2,43) = 34.69, p < 0.05, \eta_p^2 = 0.617$.

Upon taking further detailed feedback, we got some valid reasons that support the above hypothesis. According to majority of the users, as the application was portable and gave them a realistic experience, it was more convenient for them to just drop a portal and get the book instead of going to an actual library. While the rest of the users preferred the experience of an actual library and using the online libraries as they were more accustomed to these socially accepted methods, and also were quite hesitant towards the change. In Fig. 9c, we can clearly see that most of the users found our proposed application and typical type and search methods way more convenient than the traditional library. Moreover, it can also be seen that the proposed application is almost 10% more convenient than the type and search.

5.3 Task Load

Evaluations from NASA TLX showed several differences in the perceptions of various task loads between the three methods. It also showed the overall mean for those task loads. We performed the repeated measures ANOVA upon all the six factors of NASA TLX with the following results:

- Mental Demand: $Wilks'Lambda = 0.67, F(2,43) = 10.587, p < 0.05, \eta_p^2 = 0.33$

- Physical Demand: $Wilks'Lambda = 0.15, F(2,43) = 124.518, p < 0.05, \eta_p^2 = 0.853$

- Temporal Demand: $Wilks'Lambda = 0.645, F(2,43) = 11.850, p < 0.05, \eta_p^2 = 0.355$

- Performance: $Wilks'Lambda = 0.546, F(2,43) = 17.898, p < 0.05, \eta_p^2 = 0.454$

- Effort: $Wilks'Lambda = 0.414, F(2,43) = 30.381, p < 0.05, \eta_p^2 = 0.0586$

- Frustration: $Wilks'Lambda = 0.546, F(2,43) = 17.898, p < 0.05, \eta_p^2 = 0.454$

Upon examining the task loads of individual methods in Fig. 10, using a traditional library revealed a much higher task load in almost all the attributes of NASA TLX (except mental) than any of the other two methods. It is indeed peak to peak with the type and search method in the case of Mental demand. On comparing it with the proposed application, the overall work load for the application has revealed itself to be much lower (25.5%) than that of the traditional library.

After the first look at the tasks, one would expect for the overall workload of type and search method to be lower than the proposed application as there was no movement involved and also comparatively the task was really simple. However, it came out to be much higher than what we expected. The overall workload for type and search method is 47.6%, which makes it 10.3% higher than that of the proposed application. Hence, it makes the overall workload for our proposed application the least as compared to any of the other two methods.

5.4 User Preferences

Fig. 11 shows that according to most of our users (75.6%), the proposed application is much better for the navigation inside the library as compared to the traditional library. Due to the smaller walking space and interchangeable sections, the navigation in the virtual library is extremely easy e.g. (*p23: "As there was only small space to search for the book, it was really easy for me to find that book. And also I was able to switch between the sections quickly"*). Only a couple of shelves in one virtual section gives the application it's easier and faster navigation (*p16: "Easy and faster navigation"*). However, some participants still found it difficult to locate the book suggesting, e.g. *p6: "Need direction arrow for finding book location"*. Participants also reported that the multiple interchangeable sections made it highly likeable and helpful in the case of large libraries e.g. (*p2: "Its easy to use and can be very helpful for very large libraries"*).

Although the majority of our users did not encounter any problems while operating the application, some faced the following common issues during the survey: difficulty scanning the surfaces (reported by 17.8% of users), difficulty keeping the AR images in view (reported by 17.8% of users) and most importantly, difficulty using gaze as an input (reported by 22.2% of users).

Due to the portability of our proposed application e.g. (*p7: "Can be opened anywhere", p8: "Library in my pocket"*), better navigation e.g. (*p15: "Not much walking but I get the same experience", p38: "Big time saver with similar experience"*) and least overall workload e.g. (*p41: "Similar experience with less effort"*), the majority of the participants preferred the proposed application over the actual traditional library. The user distribution based on their preference of the proposed application over the traditional library can be seen in Fig. 12.

Despite the fact that the type and search is a less physically demanding method, the majority of our users preferred to have an experience of actually being in the library e.g. (*p15: "I prefer the traditional library experience"*). Additionally, the interactive aspect e.g. (*p37: "Yes, it is interactive, easy and something different. I would love to see more of it"*) of the application appealed the users and preferred the proposed application over the type and search method. At the same time, participants not familiar with using online libraries also preferred the proposed application over type and search. In Fig. 13, we can see the distribution of users based on their preferences.

Finally, in Fig. 14, we show the distribution of users based on their overall rating responses on a scale of one to five stars; where one being the least favourite and five being the most.

6. CONCLUSION

To sum it all up, in this paper, we proposed a novel application to provide users with an experience of visiting an entire library while actually being in a tiny play space using Marker-less AR. We also investigated various other methods for the same task to draw a comparison between the proposed method and two other socially accepted methods. A user study was conducted with 45 participants which revealed various flaws in existing techniques and showed how the proposed application can bring positive advancements in the ways we explore libraries. NASA TLX showed that using a traditional library had the highest workload. Upon further evaluation, we found that the proposed application had the least overall workload and was the most preferred method by the participants. The survey also further established that the navigation in the proposed application is much better than that in the traditional library. Traditional libraries use cumbersome taxonomy system which is implicitly used for the navigation. The proposed application uses smaller and contained walking area making the physical workload experienced by the users far less, hence more than 71% of the participants opted to definitely not
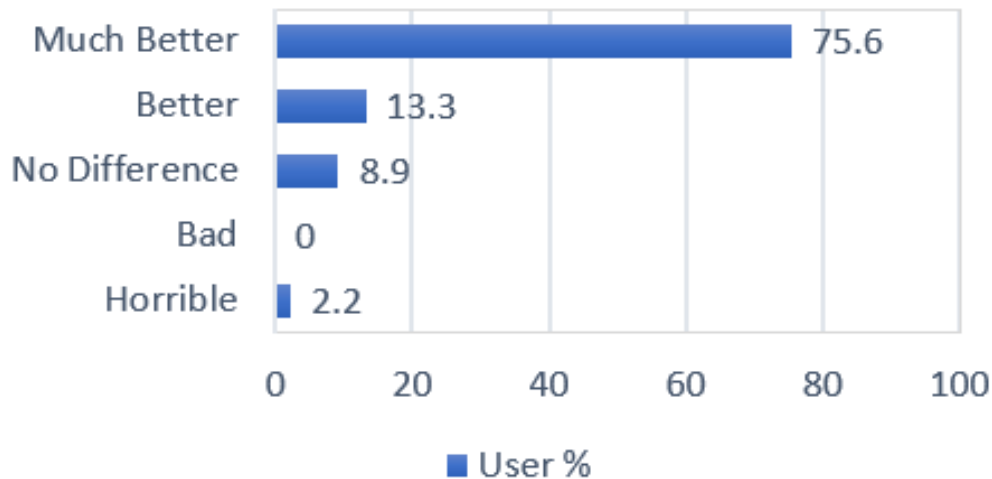

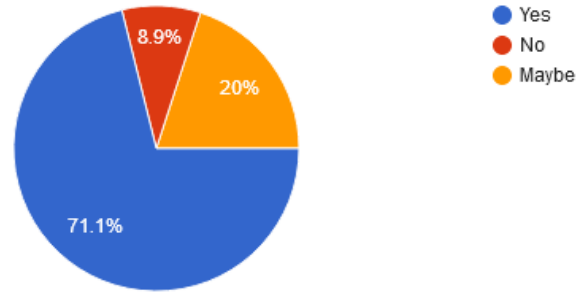Figure 11: Navigation in the proposed application as compared to the Traditional Library

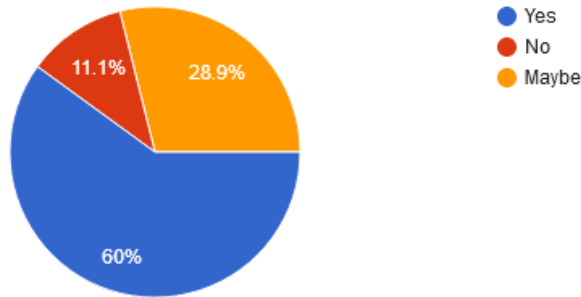Figure 12: User preference of the proposed application over the traditional library

Figure 13: User preference of the proposed application over the type and search
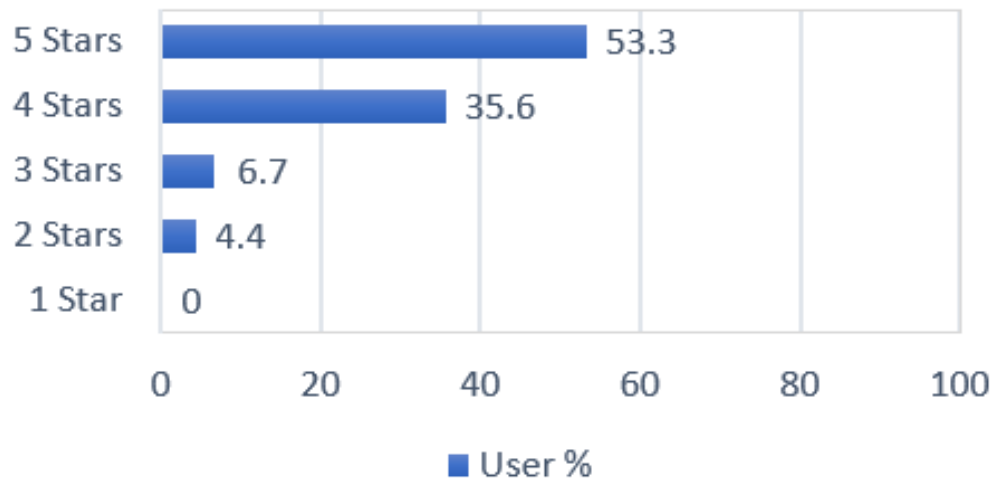

Figure 14: Overall user rating for the proposed application

prefer the traditional library and switch to using the proposed application in the future. In the case of the type and search, as our application provided a realistic library experience at their fingertips, 60% of the participants preferred the application. Overall, the participants gave our application a combined rating of 4.74 out of 5.

For future works, this application will be imported to an immersive AR platform e.g. Microsoft's Hololens. Various additional interaction techniques will be explored in order to improve the interaction. Currently, this application consists of 7800 books, however we are in the process of expanding the database to our University's library's database which houses thousands of books.

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REFERENCES

[1] R.T. Azuma, *A survey of augmented reality*, PRESENCE: Teleoperators and Virtual Environments, Vol. 6, Issue 4, pp. 355-385, August 1997

[2] Craig, Alan B. (2013). *Understanding Augmented Reality: Concepts and Applications*, Amsterdam. Retrieved from https://www.sciencedirect.com/book/9780240824086.

[3] I.E. Sutherland, *A head-mounted three dimensional display* from Proceedings of the AFIPS Fall Joint Computer Conference, Washington, D.C., Thompson Books, pp. 757-764, 1968.

[4] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, B. MacIntyre, *Recent advances in augmented reality*, IEEE Computer Graphics and Applications, Vol. 21, Issue 6, pp. 34-47, 2001.

[5] M. Akcayr, G. Akcayr, *Advantages and challenges associated with augmented reality for education: A systematic review of the literature*, Educational Research Review, Vol. 20, pp. 1-11, February 2017.

[6] Y. Pang, M.L. Yuan, A.Y.C. Nee, S.K. Ong, K. Youcef-Toumi, *A markerless registration method for augmented reality based on affine properties*, Proceedings of the 7th Australasian User interface conference, Vol. 50, pp. 25-32, January 2006.

[7] I. Barandiaran, C. Paloc, M. Graa, *Real-time optical markerless tracking for augmented reality applications*, Journal of Real-Time Image Processing, Vol. 5, Issue 2, pp. 129-138, 2009.

[8] T.W. Kao, H.C. Shih, A study on the markerless augmented reality for picture books, Proceedings of the IEEE International Symposium on Consumer Electronics (ISCE), pp. 197-198, 2013.

[9] X. Yang, K.T.T. Cheng, Accelerating SURF detector on mobile devices, Proceedings of the ACM International Conference on Multimedia, pp. 569-578, 2012.

[10] E. Cieza, D. Lujan, *Educational Mobile Application of Augmented Reality Based on Markers to Improve the Learning of Vowel Usage and Numbers for Children of a Kindergarten in Trujillo*, Procedia Computer Science, Vol. 130, pp. 352-358, 2018.

[11] Young-geun Kim, Won-jung Kim, *Implementation of Augmented Reality System for Smartphone Advertisements*, Intl. Journal of Multimedia and Ubiquitous Engineering, Vol. 9, Issue 2, pp. 358-392, 2014.

[12] A. Shatte, J. Holdsworth, I. Lee, *Mobile augmented reality based context-aware library management system*, Expert Systems with Applications, Vol. 41, Issue 5, pp. 2174-2185, April 2014.

[13] A.K. Dash, S.K. Behera, D.P. Dogra, P.P. Roy, *Designing of marker-based augmented reality learning environment for kids using convolutional neural network architecture*, Elsevier/Displays, Vol 55, pp. 46-54, Dec. 2018.

[14] M. Sagayam K., C.C. Ho, L. Henesey, R. Bestak, *3D scenery learning on solar system by using marker based augmented reality*, 4th International Conference of the Virtual and Augmented Reality in Education, pp. 139-143, November 2018.

[15] J. Li, M. Slembrouck, F. Deboeverie, *A hybrid pose tracking approach for handheld augmented reality*, Proceedings of the 9th International Conference on Distributed Smart Camera, pp. 7-12, September 2015.

[16] R. A. Sansone, L. A. Sansone, *Cell Phone: The Psychological Risks*, Innovations in clinical neuroscience, Vol. 10, Issue 1, pp. 33-37, Jan. 2013.

[17] T.R. Meredith, *Using Augmented Reality Tools to Enhance children's Library Services*, Technology, Knowledge and Learning, Vol. 20, Issue 1, pp. 71-77, April 2015.

[18] M. Siegrist, C.Y. Ung, M. Zank, M. Marinello, A. Kunz, C. Hartmann, M. Menozzi, *Consumers' food selection behaviors in three-dimensional (3D) virtual reality*, Food Research International, Vol. 117, pp. 50-59, March 2019.

[19] A. Steed, S. Julier, *Design and implementation of an immersive virtual reality system based on a smartphone platform*, 2013 IEEE Symposium on. 3D User Interfaces (3DUI), IEEE, pp. 43-46, March 2013.

[20] W. Powell, V. Powell, P. Brown, M. Cook, J. Uddin, *Getting around in google cardboard exploring navigation preferences with low-cost mobile VR*, 2016 IEEE 2nd Workshop on Everyday Virtual Reality (WEVR), Greenville, SC, pp. 5-8, March 2016.

[21] F. Biocca, *The cyborg's dilemma: Progressive embodiment in virtual environments*, Journal of computer-mediated communication, Vol. 3, Issue 2, JCMC324, September 1997.

[22] F. Biocca, C. Harms, J. Gregg, *The networked minds measure of social presence: Pilot test of the factor structure and concurrent validity*, 4th annual international workshop on presence, pp. 1-9, May 2001.

[23] J.M. Loomis, J.J. Blascovich, A.C. Beall, *Immersive virtual environment technology as a basic research tool in psychology*, Behavior research methods, instruments, and computers, Vol. 31, Issue 4, pp. 557-564, December 1999.

[24] J.M. Loomis, R.G. Golledge, R.L. Klatzky, *Navigation system for the blind: Auditory display modes and guidance*, Presence: Virtual and Augmented Reality, Vol. 7, Issue 2, pp. 193-203, April 1998.

[25] P. Cipresso, I.A. Chicchi Giglioli, M. Alcaiz Raya, G. Riva, *The past, present, and future of virtual and augmented reality research: a network and cluster analysis of the literature*, Frontiers in psychology, Vol. 9, pp. 2086, November 2018.

[26] F. Hendajani, A. Hakim, S.A. Sudiro, G.E. Saputra, A.P. Ramadhana, *Tracking Visualization Of 3 Dimensional Object Natural Science Learning Media In Elementary School With Markerless Augmented Reality Based On Android*, Journal of Physics: Conference Series, Vol. 1192, No. 1, pp. 012055, March 2019.

[27] A. Comport et al., *Real-time markerless tracking for augmented reality: the virtual visual servoing framework*, IEEE Transactions on Visualization and Computer Graphics , Vol. 12, No. 4, pp. 615-628, June 2006.

[28] B. Massis, *Using virtual and augmented reality in the library*, New Library World, Vol. 116, No. 11/12, pp. 796-799, November 2015. Retrieved from http://dx.doi.org/10.1108/NLW-08-2015-0054

[29] J. Hahn, *Mobile augmented reality applications for library services*, New Library World, Vol. 113, No. 9/10, pp. 429-438, September 2012. Retrived from https://doi.org/10.1108/03074801211273902

[30] G. Armstrong, J. Hodgson, F. Manista, M. Ramirez, *The SCARLET Project: Augmented reality in special collections*, Society of College, National and University Libraries focus, Vol. 54, pp. 52-57, 2012.

[31] J. Arnhem, J. Spiller *Augmented Reality for Discovery and Instruction*, Journal of Web Librarianship, Vol. 8, Issue 2, pp. 214-230, May 2014.

[32] M. Whitchurch, *A Quick Response: QR Code Use at the Harold B. Lee Library*, The Reference Librarian, Vol. 53, Issue 4, pp. 392-402, October 2012.

[33] J. Bradley, N. Henshaw, L. McVoy, A. French, K. Gilbertson, L. Becksford, E. Givens, *Creation of a library tour application for mobile equipment using iBeacon technology*, Code4lib Journal, Issue 32, April 2016.

[34] C.M. Chen, Y.N. Tsai, *Interactive augmented reality system for enhancing library instruction in elementary schools*, Computers and Education, Vol. 59, Issue 2, pp. 638-652, September 2012.

[35] B.E. Mulch, *Library orientation transformation*, Knowledge quest, Vol. 42, Issue 4, pp. 50-53, April 2014.

[36] R.A.M. Rodrguez, M.O.M. Rivero, *Information skills training through mobile devices: Practical applications of QR codes in academic libraries*, The Electronic Library, Vol. 34, Issue 1, pp. 116-131, February 2016.

[37] T. Langlotz, C. Degendorfer, A. Mulloni, G. Schall, G. Reitmayr, D. Schmalstieg, *Robust detection and tracking of annotations for outdoor augmented reality browsing*, Computers and graphics, Vol. 35, Issue 4, pp. 831-840, August 2011.

[38] S.H.P. Won, W.W. Melek, F. Golnaraghi, *A Kalman/particle filter-based position and orientation estimation method using a position sensor/inertial measurement unit hybrid system*, IEEE Transactions on Industrial Electronics, Vol. 57, Issue 5, pp. 1787-1798, September 2009.

[39] J.M. Andujar, A. Mejas, M.A. Mrquez, *Augmented reality for the improvement of remote laboratories: an augmented remote laboratory*, IEEE transactions on education, Vol. 54, Issue 3, pp. 492-500, October 2010.

[40] C. Onime, O. Abiona, *3D mobile augmented reality interface for laboratory experiments*, International Journal of Communications, Network and System Sciences, Vol. 9, Issue 4, pp. 67, April 2016.

[41] Sutcliffe, A. G., Poullis, C., Gregoriades, A., Katsouri, I., Tzanavari, A., & Herakleous, K. (2019). Reflecting on the design process for virtual reality applications. International Journal of HumanComputer Interaction, 35(2), 168-179.

[42] Christou, C., Tzanavari, A., Herakleous, K., & Poullis, C. (2016, April). Navigation in virtual reality: Comparison of gaze-directed and pointing motion control. In 2016 18th Mediterranean Electrotechnical Conference (MELECON) (pp. 1-6). IEEE.